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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(54) Title: METHOD AND APPARATUS FOR NEUTRALISING SPACE CHARGE IN AN ION BEAM
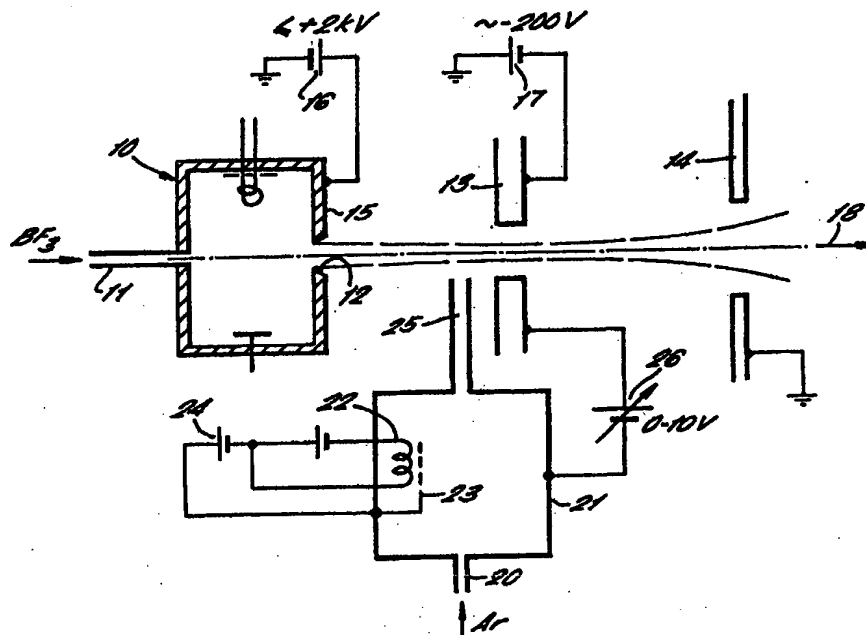
(57) Abstract

Space charge effects in an ion implanter can be caused by the mutual repulsion of ions of a particular polarity in a beam of ions which tend to cause the beam to "blow up" and become uncontrollable. This occurs for example in the ion implanter along the path of the ion beam and in particular at regions of external electric field. Introducing into the ion beam a sec nd polarity of ions space charge neutralises the ion beam.

METHOD AND APPARATUS FOR NEUTRALISING
SPACE CHARGE IN AN ION BEAM

5   The present invention is concerned with
neutralising space charge in ion beams.

Ion beams may be used for a number of purposes.
In particular, ions of desired dopant species can be
implanted in semiconductor substrates. So called "ion
10   implanters" produce a beam of ions of the required
dopant species which is directed at the substrate to
implant the ions into the semiconductor material.

In the absence of any neutralising effect, a beam
containing only ions of a particular polarity will
15   experience space charge effects. The mutual repulsion
of the ions in the beam tends to cause the beam to
"blow up" and become uncontrollable. In regions of
zero electric field, self neutralisation of ion beams
tends to occur, through the production of electrons
20   resulting from collisions between beam ions and slow
moving atoms of residual gas in the vacuum chamber
through which the beam is passing. However, in
regions of electric field, for example when the ions
of the beam are being accelerated or decelerated, or
25   the beam is being electrostatically deflected,
neutralising electrons are quickly removed from the
beam because of their high mobility.

It is therefore a problem to control ion beams
and prevent beam blow up, especially in regions
30   containing an external electric field. The effect of
beam space charge is especially severe for relatively
low energy beams, since for the same beam current,
there is a higher density of ions in a low energy
beam.

35   In machines, such as ion implant rs, where it is

- 2 -

required to present a beam having a predetermined
energy onto a target, particular problems arise where
the ion beam is first extracted from the ion source,
and elsewhere over the beam path where the beam energy

5   is changed, particularly where the beam is decelerated
prior to hitting the target. In the case of
extraction of ions from an ion source, the need to
obtain a usefully high beam current limits the minimum
energy at which ions can be extracted from the arc

10   chamber of the source. The region between the exit
window of the source arc chamber and the extraction
electrode is a region of substantial electric field in
which electrons cannot exist for significant times.
In the extreme, for high currents and low extraction

15   energies, the theoretical density of ions in the beam
leaving the source produces a beam potential similar
to the potential on the extraction electrode. Clearly
in such a case, the ions in the beam will not
experience the required accelerating field and no beam

20   is in fact produced. In fact, space charge effects
can severely reduce the extraction efficiency from ion
sources at low extraction energies.

    In ion implanters, it has therefore been the
usual practice to extract ions from the ion source at

25   no less than a minimum extraction energy, typically
not less than 10 keV, and for good efficiency often at
higher energies. In order to present a beam of lower
energy onto the target substrate, the beam must be
subsequently decelerated, and space charge problems

30   then arise also in the region of the decelerating
field.

    There is accordingly a requirement for some
mechanism for the efficient extraction of ions from an
ion source at relatively low energies, and more

35   generally for arrangements for controlling and

neutralising space charge effects in ion beams,
especially in regions of externally applied electric
field.

According to the present invention, a method of
neutralising space charge in an ion beam comprising
ions of a first polarity, comprises the steps of
generating ions of a second polarity, and introducing
said second polarity ions to space charge neutralise
the ion beam.

The ions of second polarity should be ions of
species which can be tolerated in the ion beam
process. For example in an ion implantation process
the ions may be of atoms such as He, Ne, Ar, Kr or Xe,
or of molecules such as N_2, CO_2, CO_2, CO, O_2, Cl_2, Br_2,
I_2. In each instance, the selection of an appropriate
species is dependent on the need to avoid unwanted
reactions and effects in the beam process. For
example O_2 would not be suitable for neutralising an
ion beam being extracted from an ion source employing
a hot cathode, such as a Bernas source, as the O_2
would quickly corrode the cathode. However O_2 may be
tolerated with R.F. or microwave energised ion
sources.

For effective space charge neutralisation, the
density of ions of the first polarity in a region of
the ion beam should equal the density of charged
particles of the opposite polarity, assuming both the
ions and particles are singly charged. However, the
density of charged particles in a beam is proportional
to the current density of those particles in the beam
and inversely proportional to the velocity of the
particles in the beam direction. The velocity of
charged particles, on the other hand, is proportional
to the square root of the energy of the particles and
inversely proportional to the square root of the mass

- 4 -

of the particles.

The overall effect is that singly charged
particles of high mass will have much lower
velocities, for the same energy, than lighter
5   particles and especially when compared with electrons.
Thus, beam space charge can be effectively neutralised
with opposite polarity ions in regions of the beam
where neutralisation by electrons may not be possible.

In order to reduce the current density of the
10 second polarity ions in the beam, in a region of
applied electric field, required to maintain
neutralisation, the mass of the second polarity ions
should be as high as possible. Large molecules,
including organic molecules may then be useful, such
15 as $B_{10}H_{12}$, C_xH_y (hydro-carbons) or C_xH_yOH (alcohols).
Alternatively large cluster ions may be employed.

Preferably, the second polarity ions should have
a mass/charge ratio of at least 400.

In a preferred example, the method includes
20 applying an external electric field to a region of the
ion beam and introducing said second polarity ions in
said region. As explained previously, beam
neutralisation problems arise especially in regions of
external electric field.

25 Then said second polarity ions are accelerated by
said external electric field in a field gradient
direction, and said second polarity ions may be
introduced at a location in said region which is
upstream relative to said field gradient direction.

30 It is normal practice in ion beam machines where
a positive ion beam is accelerated or decelerated
between a first electrode at a first potential and a
second electrode at a second higher potential, to
provide an electron suppression electrode between the
35 first and second electrodes at a potential which is

more negative than that of the first electrode, to
prevent electrons being drawn from the beam beyond the
first electrode by the influence of the potential on
the second electrode. Then, for such a positive ion
5   beam, ions of negative polarity are preferably
introduced adjacent to the electron suppression
electrode.

The invention also provides apparatus for
neutralising space charge in an ion beam, comprising
10   means producing a beam of ions of a first polarity,
means generating ions of a second polarity, and means
introduced said second polarity ions to space charge
neutralise the ion beam.

Examples of the present invention will now be
15   described with reference to the accompanying drawing
which is a schematic illustration of an ion source for
positive ions with an extraction arrangement
incorporating an example of the present invention.

Referring to the Figure, an ion source comprises
20   an arc chamber 10 which may be configured as a Bernas
source, or any other known ion source. A feed gas,
here shown as BF_3 is supplied to the arc chamber along
a pipe 11 and the arc chamber operates to create a
plasma within the arc chamber in which are formed the
25   ions B^+ and BF_2^+, for example. These positive ions are
then extracted from the arc chamber via an exit
aperture 12 to form a beam. In the described example,
the source is providing a beam of boron ions (or BF_2
ions) which may be useful for implanting a silicon
30   substrate with boron. However, other ions may be
produced where required, such as As^+, P^+ or Ar^+, for
example.

The ions are extracted from the arc chamber 10 by
the electric fields produced by electrodes 13 and 14.
35   To extract positive ions from the source, the arc

- 6 -

chamber 10 and in particular the front face 15
containing the exit aperture 12 is held at a positive
potential relative to the electrodes 13 and 14. In
practice, the electrode 14 may form the entrance
5   aperture to a mass analysing magnet and will usually
be at ground potential. The mass analysing magnet and
a subsequent mass selection slit are used to select
from the ions drawn from the arc chamber 10 ions of
the precise mass required for implanting. For
10   example, the mass analyser and mass selection slit may
select only B^+ ions for onward transmission to the
semiconductor substrate target. Neither the mass
analyser magnet nor the subsequent elements of the
beam path to the substrate target are illustrated in
15   the drawing. These components may be typical of those
customarily used in this art.

    In order to ensure that ions entering the mass
analyser magnet, passing through the electrode 14,
have a well defined energy, the potential of the front
20   face 15 of the arc chamber 10 is controlled by a power
supply 16. In the illustrated example, power supply
16 applies a potential of about 2 kV or less to the
front face, so that the energy of the beam in the mass
analyser will be correspondingly 2 keV or less
25   depending on the potential applied.

    The electrode 13 constitutes an electron
suppression electrode and is set by a power supply 17
at a negative potential relative to the electrode 14
so as to prevent electrons in the beam downstream of
30   the electrode 14, in the direction of the arrow 18
from being drawn out of the beam by the positive
potential on the arc chamber 10. In this way, space
charge neutralisation within the analyser magnet,
downstream of the electrode 14, is largely maintained.
35   In the described example, the potential on the

suppression electrode 13 is about -200 volts, but
suppression potentials of several kilovolts below the
ground potential of the analyser magnet and electrode
14 may be used.

5   As can be seen in the drawing, a substantial
electric field exists between the exit aperture 12 of
the arc chamber and the suppression electrode 13, and
also, though to a lesser extent, between the
suppression electrode 13 and the ground electrode 14

10   at the entrance to the mass analyser. In these
regions, any electrons in the beam have very short
residence times due to their small mass and high
mobility. As a result, space charge neutralisation by
electrons in the beam in these regions is ineffective.

15   In the described example, a source of argon gas
is supplied along a pipe 20 to expand in a chamber 21.
The sudden expansion of the argon gas in the chamber
21, causes clusters of argon atoms to condense
together, producing clusters each of at least 100

20   atoms and in appropriate conditions, up to 1000 atoms
or more.

          Within the chamber 21, a heated cathode, 22 emits
electrons, which are accelerated through a grid
electrode 23. The cathode 22 is biased relative to

25   the grid 23 by a power source 24 to produce electrons
of low energy (below about 50eV). The resulting
"spray" of low energy electrons passing through the
grid 23 ionises argon clusters within the chamber 21,
forming negatively charged cluster ions. The cluster

30   ions in the chamber 21 diffuse from the chamber
through an aperture 25 immediately adjacent the
electron suppression electrode 13.

          The resulting flood of negatively charged cluster
ions emerging from the aperture 25 assists in

35   neutralising the space charge of the portion of the

- 8 -

ion beam between the exit aperture 12 of the arc chamber 10 and the suppression electrode 13.

As explained previously, for total space charge neutralisation, the density in a particular region of the ion beam of positive ions should equal the density of negative cluster ions ($N_b = N_c$).

Further, $N_b = J_b/ev_b = N_c = J_c/ev_c$, where

J_b is the current density resulting from the positive beam ions,

v_b is the velocity of those ions in the beam,

J_c is the current density in the beam of negative cluster ions, and

v_c is their velocity.

If at a particular location in the beam, the energy of the required positive ions is equal to the energy of the negative cluster ions,

$$m_b \ v_b^2 = m_c \ v_c^2,$$

where m_b is the mass of the positive ions and m_c is the mass of the cluster ions.

From the above, $J_b/J_c = v_b/v_c = \sqrt{(m_c/m_b)}$.

Cluster ions comprising between 200 and 300 argon atoms are typically formed in the chamber 21. However, taking a minimum of 100 atoms in a cluster ion, $m_c \geq 4000$ a.u. If the positive ion in the ion beam is B^+ (mass ≈ 10.8), $m_c/m_b \approx 400$ and $J_b/J_c \approx 20$.

Thus, for full space charge neutralisation in the region of the beam where both the positive ions and the negative cluster ions have the same energy, the current of cluster ions in the beam, accelerated by the electric field towards the exit aperture 12 of the arc chamber 10, must be about one-twentieth of the beam current of boron ions from the arc chamber. For a typical boron beam current of 5 mA, this implies a cluster ion current of 0.25 mA.

In the Figure, a power supply 26 is illustrated

connected to apply a negative bias to the cluster ion
source relative to the electron suppression electrode
13. In fact, the cluster ion source may be held at
the same potential as the suppression electrode 13,
5   relying on any residual positive charge in the ion
beam to draw cluster ions from the aperture 25 and
into the beam. However, a small negative bias may
additionally be applied to the cluster ion source to
control the flow of cluster ions.

10   In the illustrated example, the cluster ion
source is shown delivering cluster ions on the
upstream side of the suppression electrode. Since the
potential difference between the arc chamber 10 and
the suppression electrode 13 is likely to be greater
15   than that between the suppression electrode 13 and the
grounded electrode 14, the problem of space charge
suppression in this region is most severe, especially
if it is desired to extract relatively high currents
at low energy from the arc chamber 10. However,
20   cluster ions may also be delivered on the other side
of the suppression electrode 13 to neutralise space
charge of the ion beam in the region between the
suppression electrode 13 and the grounded electrode
14.

25   The example of the invention described above
refers to a positive ion beam comprising boron ions.
However, the invention is applicable equally to other
desired positive ion beams. The invention may also be
applied to beams of negative ions, in which case
30   positive cluster ions are introduced. Positive
cluster ions may be formed in the chamber 21 by
spraying the condensed clusters of atoms with
electrons of higher energy.

Further, the above examples describe using argon
35   cluster ions. Other gases may be used which can be

made to produce large clusters of atoms. For ion
implantation purposes, the cluster ions should be of a
species which can be tolerated in the implantation
process. Further, for minimum mobility of the cluster
5   ion in the electric field regions of the ion beam,
relatively heavy atoms are preferred such as xenon.

Also, the above described example refers to
neutralising the ion beam at the point of extraction
from the arc chamber of the ion source. Examples of
10   the invention may be used also at other regions of a
beam where an external electric field renders the
lifetime of any electrons in the beam extremely short
so that space charge neutralisation becomes a problem.
For example, negative cluster ion neutralisation may
15   be employed in a region where the ion beam is
accelerated, and more particularly decelerated, by
means of an electric field prior to impact on a
target.

Also cluster ions may be used to provide beam
20   space charge neutralisation in a region where a beam
is scanned transversely. In this case, the cluster
ion neutralisation process described may be useful
even if the beam scanning is conducted by magnetic
fields, rather than electric fields. In such regions,
25   self neutralisation of the ion beam, by the creation
of electrons through collisions with residual gas
atoms, may be insufficient to maintain adequate
control of the beam potential. The beam may be
scanned too rapidly to allow sufficient numbers of
30   electrons to accumulate in the beam to provide
adequate neutralisation. Flooding the scanning region
with massive negative cluster ions should
substantially improve beam neutralisation.

Ions of opposite polarity may also be used for
35   neutralising an ion beam at other locations along the

beam between the ion beam source and the ion beam process target. For example, such opposite polarity ions may be injected into the ion beam containing volume of a magnet used for mass analysis (or energy analysis) of the process ion beam. Improved beam neutralisation and control may then be achieved in the magnet, especially at low beam energies and high beam currents. Opposite polarity ions may also be used to neutralise an ion beam in so called drift regions of no electric or magnetic field. Examples of drift regions in an ion implanter are between the ion source extraction optics and the entrance to the mass analysis magnet, between the mass analysis magnet and the mass resolving system, and between a post mass selection acceleration (or deceleration) stage and a substrate neutralisation system.

The invention is not restricted to the use of cluster ions for neutralising the beam. Some improvement in beam control may be achieved with ions of the second polarity (negative ions for a positive ion beam). Even He^- has a mass 4 which is about 10^4 times the rest mass of an electron ($\sim 5.5 \times 10^{-4}$ a.u.), so that the current density of He^- for the same neutralising effect is only one hundredth that for electrons. Generally, the second polarity ions should be of a species which will not have substantial deleterious effects in the process. More massive ions and cluster ions are preferred, especially for neutralising in regions of applied electric field.

- 12 -

CLAIMS

1.   A method of neutralising space charge in an ion
beam comprising ions of a first polarity, the method
5   comprising the steps of generating ions of a second
polarity, and introducing said second polarity ions to
space charge neutralise the ion beam.

2.   A method as claimed in Claim 1 including applying
10   an external electric field to a region of the ion
beam, wherein said second polarity ions are introduced
in said region.

3.   A method as claimed in Claim 2 wherein said
15   second polarity ions are accelerated by said external
electric field in a field gradient direction and said
second polarity ions are introduced at a location in
said region which is upstream in said field gradient
direction.
20

4.   A method as claimed in Claim 3 wherein said
second polarity ions have negative polarity and are
introduced adjacent to an electron suppression
electrode in the beam extraction system of a source of
25   positive ions.

5.   A method as claimed in any preceding claim
wherein said second polarity ions are cluster ions.

30   6.   A method as claimed in Claim 5, wherein said
cluster ions have a mass/charge ratio of at least 400.

7.   Apparatus for neutralising space charge in an ion
beam, comprising means producing a beam of ions of a
35   first polarity, means generating ions of a second

polarity, and means introducing said second polarity
ions to space charge neutralise the ion beam.

8.   Apparatus for neutralising space charge in an ion
5   beam, comprising a source of ions of a first polarity,
said source producing a beam of said first polarity
ions, a chamber in which ions of a second polarity are
generated, and an aperture from said chamber adjacent
to said beam through which said second polarity ions
10   diffuse to space charge neutralise said beam.
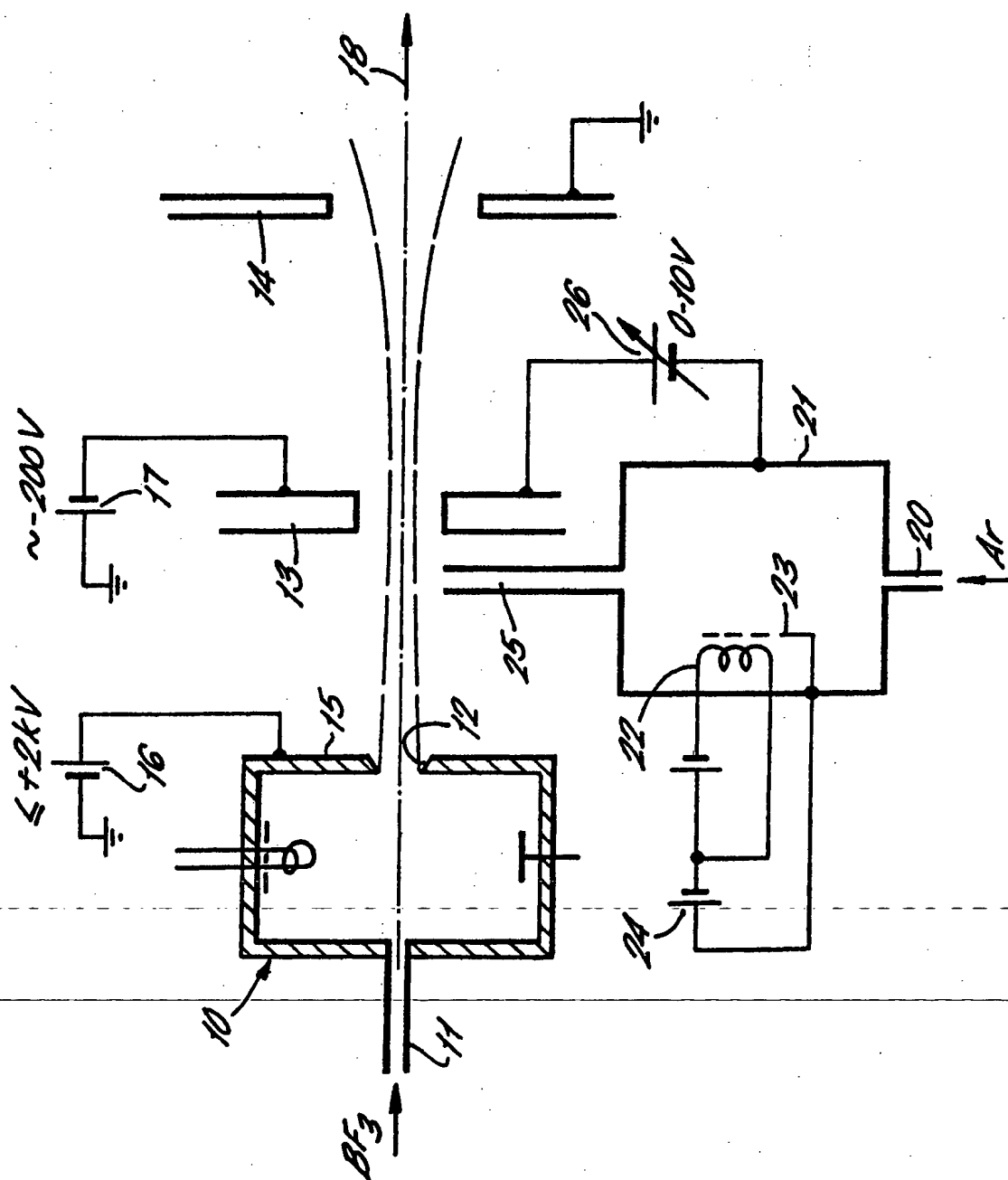
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01J27/02 H01J37/08

According to International Patent Classification(IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0 475 199 A (EBARA CORP) 18 March 1992 see abstract	1-3,7,8
Y	EP 0 774 769 A (EBARA CORP) 21 May 1997 see abstract	1-3,7,8
A	US 5 576 538 A (SAKAI KATSUHIKO ET AL) 19 November 1996 see abstract	1,7,8

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
15 October 1998	22/10/1998

Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Hulne, S

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